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## Article

# Hemodynamic Changes in Supra Aortic Trunks after Transcatheter Aortic Valve Implantation at Duplex Ultrasound Examination

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**Abstract:** Background/Objective: The hemodynamic consequences of the aortic stenosis (AS) on supraortic trunks may have a potential role in the diagnosis of concomitant internal carotid artery (ICA) stenosis by dampening blood flow velocity. To investigate the effect of AS on ICA blood flow we evaluated carotid and vertebral blood flow velocity indexes in patients undergoing transcatheter aortic valve implantation (TAVI). Methods: Eighty-five patients admitted for endovascular treatment of a severe AS underwent supra-aortic Duplex ultrasound (DUS) examination prior and after TAVI to be enrolled in the study. Patients with other cardiac impairments that could configure a confounding factor were excluded. Patients with symptomatic or severe ICA stenosis defined according to NASCET criteria were excluded. Results: Forty-five patients of a median age of 80 years met the study inclusion criteria. The peak systolic velocity (PSV) of the assessed supraortic arteries increased after TAVI: respectively common carotid artery (CCA)  $64 \pm 17$  cm/s vs  $78 \pm 23$  cm/s,  $p = 0,01$ ; ICA  $68 \pm 23$  cm/s vs  $96 \pm 35$  cm/s,  $p = 0,01$ ; vertebral artery (VA)  $45 \pm 14$  cm/s vs  $52 \pm 15$  cm/s,  $p = 0,03$ . Similarly, the end diastolic velocity (EDV) increased after TAVI: respectively CCA  $13 \pm 6$  cm/s vs  $15 \pm 7$  cm/s,  $p = ns$ ; ICA  $20 \pm 9$  cm/s vs  $24 \pm 9$  cm/s,  $p = 0,01$ ; VA  $9 \pm 4$  cm/s vs  $11 \pm 4$  cm/s,  $p = 0,01$ . Consistently, the mean acceleration time (AC) decreased after TAVI: respectively CCA  $0,17 \pm 0,05$  s vs  $0,12 \pm 0,05$  s,  $p = 0,01$ ; ICA  $0,18 \pm 0,05$  s vs  $0,12 \pm 0,04$  s,  $p = 0,01$ ; VA  $0,16 \pm 0,05$  s vs  $0,11 \pm 0,05$  s,  $p = 0,02$ . Conclusions: Severe AS significantly affects supra-aortic arteries blood flow as assessed by duplex, by decreasing both PSV and EDV and increasing AC. This study suggests that carotid ultrasound criteria to assess ICA stenosis severity should be re-evaluated in larger multicenter studies to validate their predictive values in patients with concomitant AS.

**Keywords:** aortic stenosis; internal carotid artery stenosis; aortic valve repair; surgical aortic valve repair; TAVI; duplex ultrasound

## 1. Introduction

Aortic stenosis (AS) is the most frequent heart valve disease in elderly population and the prevalence of a concomitant internal carotid artery (ICA) stenosis  $\geq 50\%$  ranges from 13 to 33%<sup>1,2</sup>. The increased afterload of the left ventricle determined by the presence of AS results into an abnormal flow pattern distal to the aortic valve, which is characterized by a delayed upstroke, a rounded curve of the waveform which has a reduced magnitude. The typical blood flow pattern of the AS is evident at doppler spectral examination of the supraortic arteries<sup>3,4</sup> and could be advocated as a potential cause of underestimation of a carotid artery stenosis<sup>5</sup>. Duplex Ultrasound (DUS) is the gold standard

for diagnosis of ICA stenosis by visualization of the plaque and assessing blood flow velocity, the latter being the mainstem for grading obstruction severity<sup>6</sup>. Since transcatheter aortic valve implantation (TAVI) is performed without affecting chest respiratory and cardiac hemodynamic, can be considered a clinical model to investigate the role of AS on supraortic arteries blood flow duplex mediated assessment. The aim of this prospective case-control study was to evaluate the effect of a severe aortic stenosis on carotid and vertebral blood flow velocity indexes before and after TAVI.

## 2. Materials and Methods

### 2.1. Study Population

This study was approved by the institutional ethics committee (CEUR-CET/CEL 20240018953) and informed consent was obtained by all participants. From January 2022 to December 2023, eighty-five consecutive adult patients with severe aortic stenosis with high surgical risk or aged  $\geq 75$  years, and suitable for TAVI at the Division of Cardiology of the Azienda Ospedaliera San Carlo, Potenza, Italy underwent supra-aortic Duplex ultrasound (DUS) examination prior to TAVI as a part of the preoperative assessment and after the procedure for the purpose of the study. Severe AS was defined by the presence of an aortic valve area (AVA)  $< 1 \text{ cm}^2$  and/or mean transvalvular aortic gradient  $> 40 \text{ mmHg}$  and/or peak aortic jet velocity  $\geq 4 \text{ m/s}$  according to current guidelines<sup>7</sup>. Patients with carotid occlusion, reduced left ventricular ejection fraction (LVEF  $< 50\%$ ), moderate or severe aortic valve regurgitation before and/or after TAVI, uncontrolled blood pressure, tachyarrhythmias, severe anaemia or hyperthyroidism were excluded from the registry to omit other potential confounding factors that may alter carotid or vertebral blood flow.

### 2.2. Cardiac Ultrasound

Echocardiographic assessments were carried out using a Vivid E95 ultrasound system (GE Healthcare, Chicago, Illinois, United States) by the same certified physician before and after TAVI. AVA was calculated by the continuity equation, mean gradient by the simplified Bernoulli equation and left ventricular ejection fraction by the biplane Simpson method according to current guidelines<sup>8</sup>. The Doppler velocity index was measured by dividing the time-integral velocity in the left ventricular outflow tract by the time-integral velocity in the aorta. The severity of regurgitation of native valve and bioprosthesis was assessed by a multiparametric approach and according to current guidelines<sup>9,10</sup>.

### 2.3. Duplex Assessment

All DUS examinations were performed by the same certified physician using a General Electric LOGIQ E10 ultrasound system (GE Healthcare, Chicago, Illinois, United States) with a Clear linear array probe. All carotid examinations were performed with grey-scale, Color-Doppler and spectral Doppler velocity determination with an insonation angle between 40 to 60 degrees. Peak systolic velocity (PSV), end-diastolic velocity (EDV) and acceleration time (AC) were evaluated in the common, internal and vertebral artery of both sides prior and after TAVI. Symptomatic or severe carotid artery stenosis defined according to NASCET criteria<sup>11,12</sup> were excluded.

### 2.4. TAVI Procedure

All patients underwent TAVI by experienced physicians. The choice of valve type (self-expanding or balloon-expandable), its size and access site were at the discretion of the Heart team considering the comorbidities and the results of pre-procedural computed tomography. Only patients who underwent a successful TAVI defined by a mean gradient  $< 20 \text{ mmHg}$ , peak velocity  $< 3 \text{ m/s}$ , Doppler velocity index  $> 0.25$ , and less than moderate aortic regurgitation were enrolled in our study<sup>13</sup>.

2.5. Statistical Analysis

Continuous variables are expressed as mean and standard deviation or median and inter quartile range where appropriate. Categorical variables are expressed as percentages. The T-student test was utilized to compare the distribution of each variable. P values < 0.05 were considered statistically significant. R software (version 4.3.3, R Development Core Team) was utilized for calculations.

3. Results

Clinical and demographic characteristics are reported in Table 1. Among the screened patients, a total of forty-five patients (42% men) of a median age of 80 years (IQR 77 - 85) met the inclusion criteria. The mean interval time between pre and post TAVI supra-aortic blood flow indexes assessment was 5 days (IQR 3 – 9). Haemodynamic index changes of examined supraortic vessels before and after TAVI are summarized in Table 2. The PSV of the assessed supraortic arteries significantly increased after TAVI (respectively common carotid artery  $64 \pm 17$  cm/s vs  $78 \pm 23$  cm/s,  $p = 0,01$ ; internal carotid artery  $68 \pm 23$  cm/s vs  $96 \pm 35$  cm/s  $p = 0,01$ ; vertebral artery  $45 \pm 14$  cm/s vs  $52 \pm 15$  cm/s,  $p = 0,03$ ). The average increase of PSV in common, internal and vertebral arteries was 18%, 29% and 13% respectively. The EDV of the assessed supraortic arteries increased after TAVI (respectively common carotid artery  $13 \pm 6$  cm/s vs  $15 \pm 7$  cm/s,  $p = \text{ns}$ ; internal carotid artery  $20 \pm 9$  cm/s vs  $24 \pm 9$  cm/s  $p = 0,01$ ; vertebral artery  $9 \pm 4$  cm/s vs  $11 \pm 4$  cm/s,  $p = 0,01$ ). The average increase of EDV in common, internal and vertebral arteries was 9%, 17% and 14% respectively, which is statistically significantly only in ICA e VA. Finally, the mean AC of the assessed supraortic arteries significantly decreased after TAVI (respectively common carotid artery  $0,17 \pm 0,05$  s vs  $0,12 \pm 0,05$  s,  $p = 0.01$ ; internal carotid artery  $0,18 \pm 0,05$  s vs  $0,12 \pm 0,04$  s  $p = 0,01$ ; vertebral artery  $0,16 \pm 0,05$  s vs  $0,11 \pm 0,05$  s,  $p = 0,02$ ). The average decrease of AC was 50%, 42%, 39% respectively. A whisker plot underlying the main results of the study is provided in Figure 1. Spectral doppler examinations of the supra-aortic vessels after the procedures revealed no more AS related characteristics as delayed upstroke, rounded curve of the waveform and a reduced magnitude in all cases as shown in Figure 2. Notably, according to these post TAVI hemodynamic changes, two patients of this population, who preoperatively were diagnosed with non-severe internal carotid artery stenosis based on velocity estimation, overtook the threshold for severity after TAVI.

**Table 1.** Demographics, cardiovascular risk factors, comorbidities and aortic valve parameters in a cohort of 45 patients diagnosed with AS.

Variable	Value
Age, y, median (IQR)	80 (77-85)
Male, n (%)	19 (42)
Hypertension, n (%)	13 (29)
Dyslipidemia, n (%)	14 (31)
DM, n (%)	3 (7)
CKD, n (%)	4 (9)
Atrial fibrillation, n (%)	13 (29)

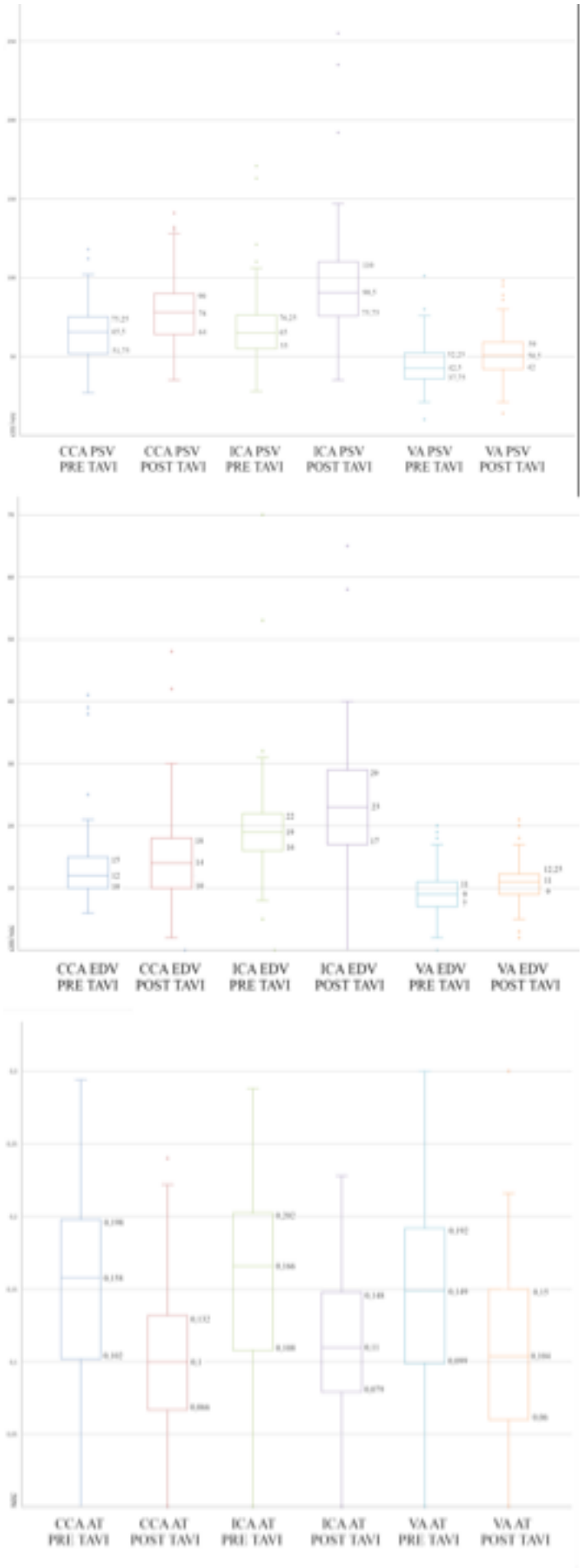
COPD, n (%)	3 (7)
CAD, n (%)	18 (40)
Previous AMI, n (%)	4 (9)
Previous CABG, n (%)	0 (0)
Previous PCI, n (%)	16 (36)
Aortic valve area, cm <sup>2</sup> , median (IQR)	0.7 (0.7-0.8)
Preoperative median TG, (IQR)	43 (40-53)
Postoperative median TG, (IQR)	12 (8-14)
Preoperative EF, median (IQR)	57 (55-61)
Mild aortic regurgitation after TAVI, n (%)	19 (42)

Data are presented as n (%) or median (inter quartile range). DM = diabetes mellitus; CKD = chronic kidney disease, defined by glomerular filtration rate < 60 ml/min; COPD = chronic obstructive pulmonary disease; CAD = coronary artery disease; AMI = acute myocardial infarction; CABG = coronary artery bypass grafting; PCI = percutaneous coronary intervention; TG = transaortic gradient; EF = ejection fraction.

**Table 2.** Supra aortic blood flow velocity indexes and their variation in a cohort of 45 patients diagnosed with AS prior and after TAVI.

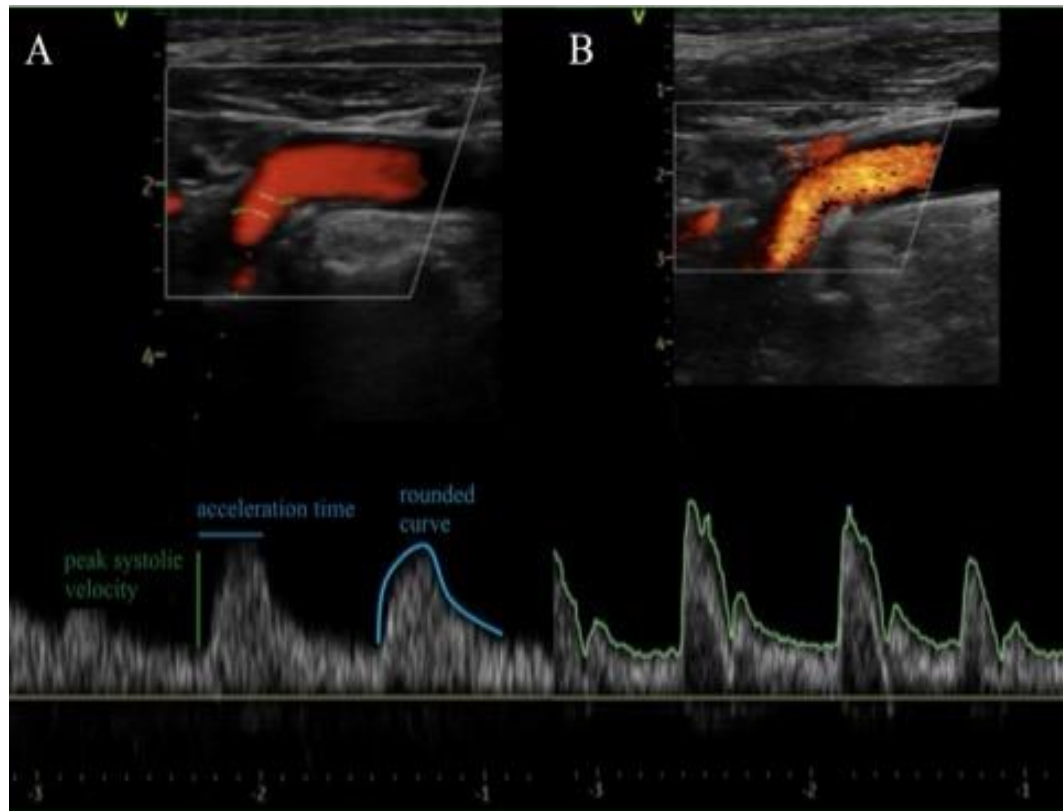
	Pre TAVI mean (SD)	Post TAVI mean (SD)	Δ %	<i>p value</i>
CCA PSV (cm/s)	64 (±17)	78 (±22)	18	0,01
CCA EDV (cm/s)	13 (±6)	15 (±6)	8	0,39
CCA AT (s)	0,168 (±0,05)	0,112 (±0,04)	-50	0,01
ICA PSV (cm/s)	68 (±23)	96 (±35)	29	0,01
ICA EDV (cm/s)	20 (±9)	24 (±19)	17	0,01
ICA AT (s)	0,177 (±0,05)	0,124 (±0,04)	-42	0,01
VA PSV (cm/s)	45 (±14)	52 (±15)	13	0,03
VA EDV (cm/s)	9 (±4)	11 (±4)	13	0,01
VA AT (s)	0,160 (±0,05)	0,115 (±0,05)	-39	0,02

SD = standard deviation; CCA = common carotid artery; PSV = peak systolic velocity; END = end diastolic velocity; AT = acceleration time; ICA = internal carotid artery; VA = vertebral artery.

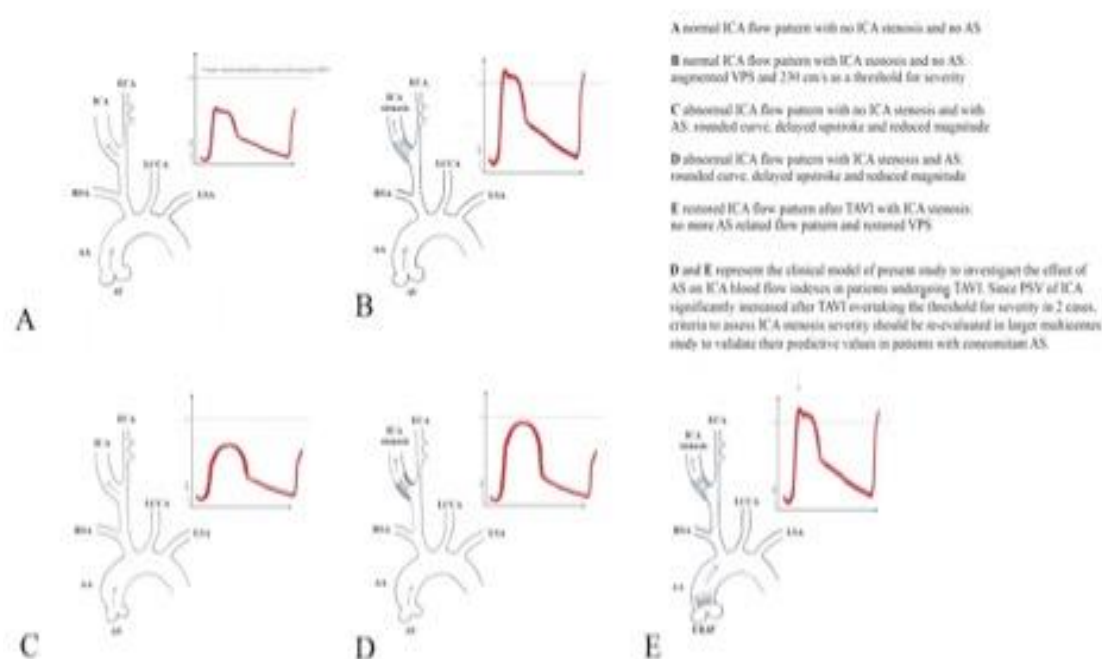




**Figure 1.** Effect of aortic stenosis on supraortic arteries duplex determined variables. Box plot of PSV (top), EDV (middle) and AT (bottom) detected on CCA, ICA and VA prior and after TAVI in a cohort of 45 patients diagnosed with AS. PSV = peak systolic velocity; EDV = end diastolic velocity; AT = acceleration time; CCA = common carotid artery; ICA = internal carotid artery; VA = vertebral artery; TAVI = transcatheter aortic valve implantation; AS = aortic stenosis.



**Figure 2.** Carotid duplex assessment before and after TAVI. Representative ecocolor Doppler with spectral curve of internal carotid artery of a patient diagnosed with severe AS showing delayed upstroke (prolonged acceleration time), rounded curve of the waveform and a reduced magnitude before TAVI in A and after the procedure in B with normalization of the spectral curve.



**Graphical Abstract.** AA = Ascending Aorta; AS = Aortic Stenosis; AV = Aortic Valve; ECA = External Carotid Artery; ERAV = Endovascular Repaired Aortic Valve; ICA = Internal Carotid Artery; LCCA = Left Common Carotid Artery; LSA = Left Subclavian artery; PSV = Peak Systolic Velocity; RSA = right Subclavian artery.

In the graphical abstract the 5 spectral wave prototypes of the ICA at DUS are reproduced.

#### 4. Discussion

The study results demonstrate the abnormal flow pattern of supraortic trunks observed at the duplex assessment in the presence of a severe AS, decrease PSV and EDV in common, internal carotid and vertebral arteries and increase AC in the same arteries. So far, hemodynamic changes in the supra-aortic arteries with coexistence of AS have been evaluated with opposite results. In a retrospective registry<sup>14</sup>, carotid artery waveform abnormalities were investigated, reviewing acceleration time, peak velocity and waveform contour of common, internal and external carotid arteries of 24 patients with various degrees of aortic stenosis. The authors reported that acceleration time increase and peak velocity decrease correlated with the severity of the aortic valve disease. These data are consistent with our study findings supporting the concept that, in the presence of aortic stenosis, the abnormal flow pattern determined by the increased afterload of the LV results in a decreased blood flow velocity in the supraortic arteries. If this pathologic effect could be reversed by eliminating the aortic stenosis was already tested in the past. In a retrospective comparison of PSV and EDV of the internal carotid artery of 92 patients prior and after surgical aortic valve repair (SAVR) no difference could be observed<sup>3</sup>. Of note, in that study, only 11% of patients underwent SAVR alone. Most patients underwent other cardiac procedures such as coronary artery bypass grafting, concurrent surgery on additional heart valves or other additional surgical procedures resulting in confounding bias. Furthermore, the mean interval between the two examinations was more than six months ( $182 \pm 98$  days). Differently in a prospective study, evaluating 30 patients undergoing aortic valve replacement for aortic stenosis, a postprocedural decreased acceleration time and an increased peak systolic velocity could be observed in all patients (Cardon et al). In our study we decided to isolate the effect of aortic stenosis of supraortic arteries blood flow by limiting our assessment only to patients undergoing isolated TAVI. In these conditions it is possible to avoid the effect of open chest surgery and other cardiac procedures on the supraortic blood flow pattern. On



this background we decided to perform a postoperative duplex scan a few hours after TAVI because we hypothesized that supraortic arteries blood flow pattern is restored to normal briefly after TAVI. In accordance with this supposition, our study demonstrated an underestimation of internal carotid artery velocity indexes in presence of an AS. This effect could affect the diagnostic accuracy of duplex carotid artery preoperative assessment.

## 5. Study Limitations

The small number of patients enrolled and the fact that DUS is an operator-dependent test represent limitations of the study. However, the population is extremely selected and rigorous methodology of DUS examination makes the risk of bias very low.

## 6. Clinical Perspectives

Prevalence of coexisting severe AS and asymptomatic ICA stenosis >50% is not negligible reaching up to one third of patients diagnosed with aortic valve disease. Despite severe carotid artery stenosis alone is not a risk factor for stroke or mortality in patients undergoing coronary artery bypass grafting<sup>17</sup> or TAVI, neurological impairments attributable to ICA disease still affect outcomes of aortic stenosis surgical treatment. Causes need to be clarified and a misdiagnosed severe asymptomatic ICA stenosis could be considered. Since present study demonstrated an underestimation of ICA stenosis severity as a result of the abnormal flow pattern induced by a severe AS, further studies investigating proper preoperative assessment of ICA stenosis of patients scheduled for SAVR are recommended to improve neurological outcomes.

## 7. Conclusions

Severe AS significantly decreases supra-aortic arteries blood flow and this effect can underestimate the grade of carotid artery stenosis. This study suggests that carotid ultrasound criteria to assess ICA stenosis severity should be re-evaluated in larger multicenter studies to validate their predictive values in patients with concomitant AS and ICA stenosis.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

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